Measurement of Absolute Energy Loss of 28 MeV Alpha Particles in Various Materials

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A method of measuring absolute energy loss and straggling of various materials for 28 MeV alpha particles is described. A broad range magnetic spectrograph was used to measure the absolute energy values. The preliminary results for Sn, Au and mylar are described.

I. INTRODUCTION

The investigation of penetration of heavy charged particles through matter is important for nuclear physics in connection with the experimental analysis. The interaction of charged particles with matter also gives the basis of the charged particle detection. Many theoretical and experimental investigations have been made up to the present. The results have been reviewed by several authors[1,2,3]. Theoretically, the stopping power of heavy changed particles is given by the following formula[4],

$$-\frac{dE}{dx}=\frac{4\pi z^2e^4}{mv^2}NZ\left\{\log\frac{2mv^2}{I}+\log\frac{1}{1-\beta^2}-\beta^2-\frac{\sum_i C_i}{Z}\right\}. \tag{1}$$

Here v is the velocity and ze is the charge of the incident particle, N the number of atoms per cubic centimeter of the material, Z the nuclear charge, m the rest mass of electron, I the mean excitation potential of the atom, β the ratio v/c and C_i the correction term which represents the deficit of the stopping power due to the ineffectiveness of the inner shell electrons. The shell corrections for K and L shells, C_K and C_L, have been calculated by Walske[5]. Bloch[6] has shown that the mean excitation potential should be proportional to the atomic number on the basis of the Fermi-Thomas statistical model of atom. That is,

$$I=kZ, \tag{2}$$

where k is a constant which must be determined from experimental data.

Experiments with reasonable accuracies have been reported up to the present. Mather and Segrè[7] measured the ranges of 340 MeV protons and derived I values for Al, Be, C, Cu and Pb. Bloembergen and van Heerden[8] made range measurements using protons up to about 115 MeV and determined I values for Al, Au and Pb. Sachs and Richardson[9] made measurements of the absolute

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energy loss of 18 MeV protons in various materials utilizing the inner beam of the cyclotron and its magnetic field. Caldwell[10] calculated the I values from Sachs and Richardson's data using Walske's[5] shell corrections. More recently, Bichsel, Mozley and Aron[11] made very accurate range measurements of 6 to 18 MeV protons in Be, Al, Cu, Ag and Au, and gave I values using Walske's[5] and Aron's[12] shell correction. Burkig and MacKenzie[13] measured relative stopping powers of 23 elements from Be to Th for 19.8 MeV protons and the I values for Be, Al, Fe, Cu, Ag. W, Au and Pb were calculated using Walske's[5] shell corrections. Nielsen[14] measured the absolute stopping power for 4 MeV protons and deuterons with a broad range magnetic spectrograph and obtained I values for Be, Al, Ni, Cu, Ag and Au.

Experimental informations of straggling are also useful for nuclear experiments. The particles with mono-energy will not lose the same amount of energy when they pass a foil with definite thickness. The standard deviation of the energy distribution gives a measure of the energy straggling. Nielson[14] made measurements of the energy straggling for various elements for 4 MeV protons and deuterons.

Most of these experiments are related with penetration of protons. No experimental data are available for alpha particles at present. Since estimation of I values from range measurements is an indirect procedure to investigate I values, it is desirable to measure the absolute energy loss for a well analyzed external beam or protons or alpha particles by the magnetic deflection method.

In the present study a method of measuring absolute energy loss and energy straggling of various materials for 28 MeV alpha particles is reported. The preliminary results have been obtained for Sn, Au, and mylar.

II. EXPERIMENTAL PROCEDURES

Alpha particles from the 105 cm cyclotron of Kyoto University were deflected by a sector type analyzing magnet and let into the reaction chamber of a broad range magnetic spectrograph. The energy spread of the analyzed alpha particles was limited to within 0.1%. The alpha particles were scattered at an angle of 30 degrees by a thin Au foil (0.17 mg/cm^2) placed at the centre of the reaction chamber. The scattered alpha particles passed through a broad range magnetic spectrograph and were recorded by means of photographic plates* placed along the focal plane. The resolution of the magnetic spectrograph is shown in Fig. 1. The detail of the magnetic spectrograph will be reported elsewhere.

The plates were exposed twice with a foil inserted in the scattered beam and then with the foil removed. The time of one exposure was about 30 minutes. The interval between the two exposures was about 20 minutes. From the difference of these energies, the average energy loss for each foil was obtained and the stopping power was given by dividing the average energy loss by the foil thickness.

* Sakura 100μ NRE-1, Konishiroku Photo Industries Co. Ltd.

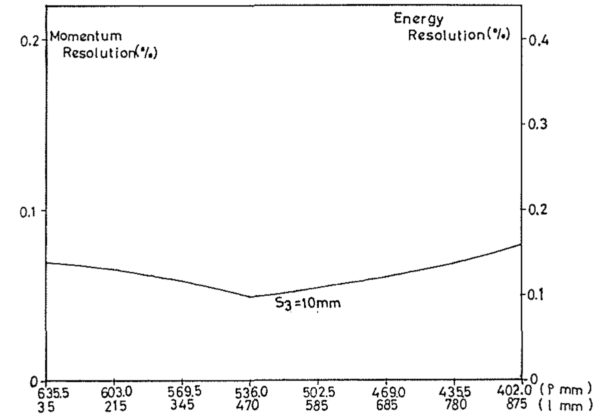

Fig. 1. The relation between the resolution of the magnetic spectrograph and the distance along the plate. The width of the object of the spectrograph is 1 mm. The symbol ρ denotes the trajectory radius and l is the distance along the plate.

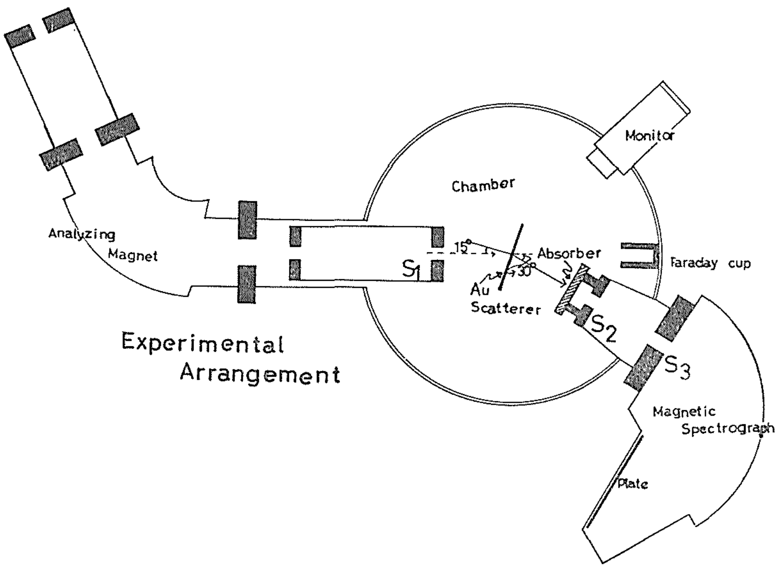

Fig. 2. The experimental arrangement.

Fig. 2 shows the experimental arrangement. The entrance silt (S_1) of the reaction chamber was chosen as 0.625 mm in height and 0.73 mm in width for the energy spread of the analyzed beam of 0.1%. The foils were inserted in the scattered beam at the distance of 5 cm from the scatterer. An additional silt (S_2) of 1.2 mm in height and 2.0 mm in width was placed immediately behind the foil. The slit (S_3) at the entrance of the magnetic spectrograph was 10.0 mm in height and 8.0 mm in width, and at the distance of 61.8 cm from the centre of the reaction chamber (the object point of the spectrograph). The slit S_3 determines the resolution of the magnetic spectrograph. The alpha particles were deflected in a vertical plane in the spectrograph.

The beam intensity was measured by a Faraday cup and a beam integrator.

A CsI counter mounted to the hole of the lid of the chamber at an angle of 45 degrees to the incident beam was used as a monitor.

In order to obtain the maximum energy resolution, the Au scatterer was placed in such a way that the normal to the scatterer was at an angle of 15 degrees (one half of the scattering angle) with respect to the incident beam.

The magnetic field of the analyzing magnet was stabilized by a current stabilizer and was measured before and after the exposure by the method of nuclear magnetic resonance, and that of the spectrograph was stabilized and measured by the method of nuclear magnetic resonance. The relation between the distance along the photographic plate placed on the focal plane and the particle trajectory radius in the spectrograph was calibrated by recording alpha particles from a Th(C+C′) source at various field strength. The energy values for Th(C+C′) alpha particles were taken from the table of Wapstra *et al.*[15]

The thicknesses of the foils were determined by measuring the weights with a balance and the area with a microscope. The sensitivity of the balance is 0.1 mg. The micrometer of the microscope stage has the division of 0.01 mm. The foils are commercial. The thickness of the foils are shown in Table 1.

Table 1. The thickness of the foils.

Material	Thicknesses (mg/cm^2)
Sn	7.05 ±0.06
Au	10.52 ±0.13
Mylar	1.223±0.010

The pressures in the reaction chamber and the magnetic spectrograph were maintained at 5×10^{-6} mmHg and 3×10^{-5} mmHg respectively.

III. RESULTS

Stopping Power

Fig. 3 (a)~(c) show the plots of the number of the tracks versus the distance along the plate obtained for each material. In each figure, the narrow peak corresponds to the alpha particles without the stopping foil. The energy spread of these peaks is less than 0.2%. Table 2 shows the primary (scattered) beam energies, the energy losses and the stopping powers. The variations of the primary beam energy were due to the operation condition of the cyclotron. The errors of the energy losses include statistical errors and the reading error of the vernier of the microscope stage. The latter error is 0.1 mm and corresponds to about 2.0 keV.

Energy Straggling

The energy straggling may be obtained from the difference of the widths of the two peaks. The width of the broad peak is due mainly to the straggling phenomenon and the distribution can be fitted to the gaussian distribution. Be-

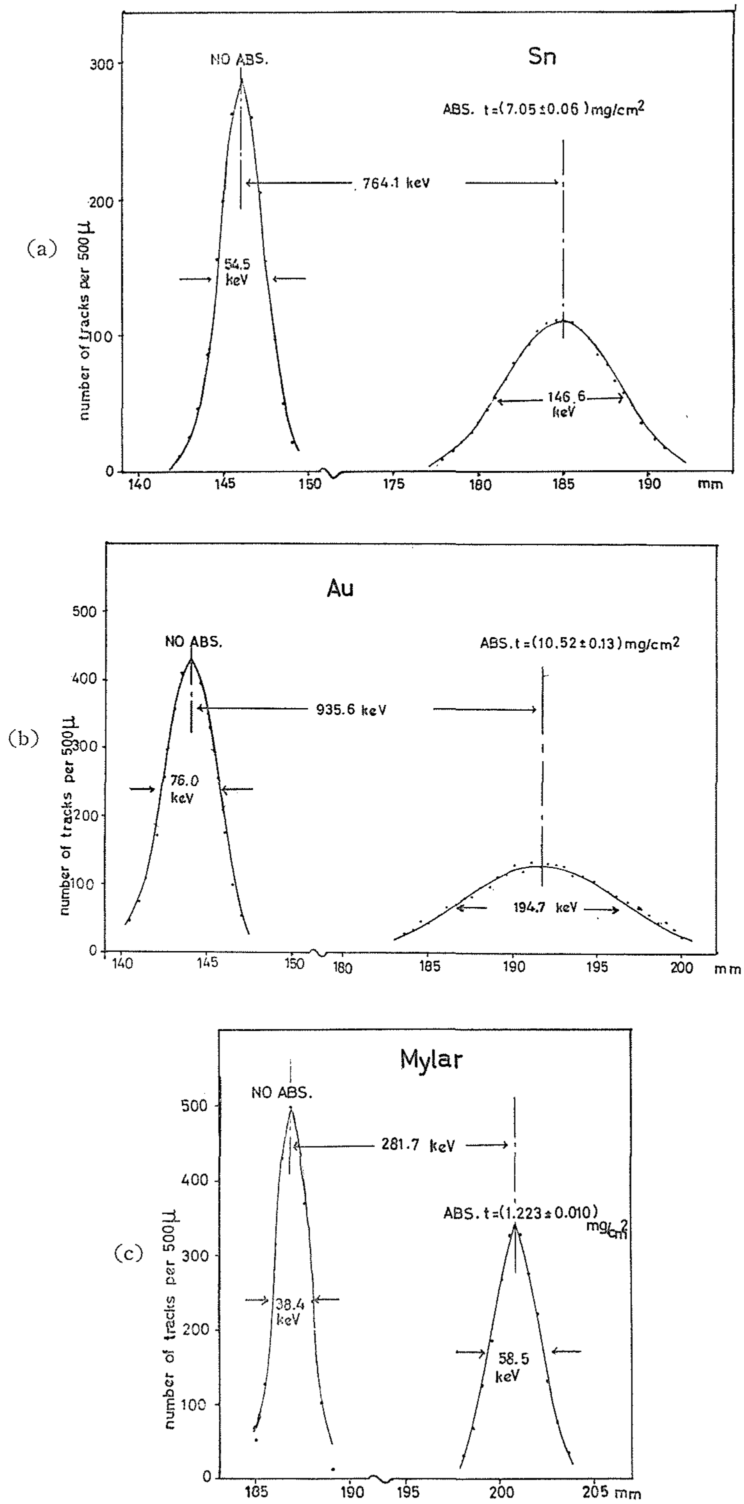

Fig. 3. The plots of the number of the tracks *versus* the distance along the plate.

Table 2. The primary energy, the energy loss and the stopping power for each foil.

Material	Primary energy (MeV)	Energy loss (keV)	Stopping power (keV. cm^2/mg)
Sn	28.7115±0.0022	764.1±3.1	104.0±1.2
Au	28.5848±0.0024	935.6±3.3	89.2±1.5
Mylar	28.2858±0.0021	281.7±3.0	230.3±2.8

cause the relation between the distance along the plate and the energy can be regarded as linear in a narrow range, the standard deviation of the energy distribution can be obtained directly from the distribution shown in Fig. 3.

If we denote twice the standard deviation of the peak with the foil inserted by Ω_1 and without the foil by Ω_0, the energy straggling Ω_2 for the foil is obtained as

$$\Omega_2^2 = \Omega_1^2 - \Omega_0^2 \tag{3}$$

One contribution to Ω_0 and Ω_1 comes from the finite resolution of the spctrograph and the analyzing magnet. Another contribution to Ω_1 may come from the multiple scattering effect in the stopping foil. This effect, however, is considered to be negligiblly small. Table 3 shows the energy straggling.

Table 3. The straggling of each material for 28 MeV alpha particles.

Material	Straggling (keV. cm^2/mg)
Sn	19.3
Au	17.0
Mylar	36.3

IV. DISCUSSION

The errors of the stopping powers given in Table 2 are less than 2 %. These errors do not include the possible drift of the primary energy during the two exposures with and without the absorber. The most important point in the present method is to keep the energy of the analyzed beam constant during the two exposures. It is preferable to obtain the data in a shorter time by using the scattered beam at more forward angles. It is perhaps more desirable to devise some method to obtain the data with and without the absorber simultaneously in one exposure. When measurements are made in such conditions, more accurate absolute values will be obtained.

Absolute measurements of the energy loss over extended Z values from 4 to 82 are in progress with improved experimental conditions.

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